

NUMERICAL STUDY OF NATURAL CONVECTION HEAT LOSS OF HEAT PIPE RECEIVER FOR DISH/STIRLING SYSTEM

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ABSTRACT

The receiver of dish/Stirling solar thermal power system is a critical component which must absorb incoming concentrated solar energy and deliver thermal power to the engine working fluid at high-flux from 40 to 80 W/cm² and temperatures of 650~850°C. The heat loss of the receiver has serious influence upon the system performance. In this paper, a numerical study on the major convection heat loss from a heat pipe receiver of dish/stirling system is presented. The influence of the operating temperature, the inclination angle and aperture size on the total heat loss from the receiver was investigated. The effect of the temperature varying from 650°C to 850°C on heat loss of the receiver was simulated. The inclination angle ranges between 0° and 90° to estimate the influence of inclination upon convection heat loss of the heat pipe receiver. The receiver aperture is always optimized to be just large enough to admit most of the concentrated sunlight, but small enough to limit radiation and convection heat loss. The effect of aperture diameter to the heat loss is also investigated. The results indicate that the natural convection heat loss is decrease monotonically with the increase of the inclination angle; the aperture diameter is a critical parameter in design of a solar receiver. The investigation conclusions can be used as reference information for the heat pipe receiver design and application.

1. INTRODUCTION

In dish/Stirling solar power system, a heat pipe receiver absorbs the solar energy that is reflected from the dish and transfers the thermal energy to the working fluid of the stirling engine. The receiver must operate in a severe environment at high temperatures up to 850°C and at solar flux intensities from 40 to about 80 W/cm²[1,2].

Heat Pipe receivers have been identified as a desirable interface to couple a Stirling engine with a parabolic dish solar concentrator [3,4]. The heat pipe receiver provides power uniformly and nearly isothermally to the engine heater heads resulting in improved engine performance. The receiver also has less thermal losses than the tube receiver. The heat pipe receiver was conceived as an improvement over directly illuminated tube receivers. In the heat pipe receiver operating in dish/stirling system, liquid metal (sodium, potassium. or NaK) is evaporated at the solar absorber and condensed at the engine heater tubes, supplying the latent heat of vaporization to the engine. There is a wick saturated with liquid metal that covers the absorber surface of the receiver. The condensate is returned to the receiver absorber by gravity, and distributed over the surface by gravity and capillary forces in a wick lining the receiver. Fig. 1[5] shows a schematic of a typical heat pipe receiver in the insulation with the heater tubes of engine.

Due to its two-phase nature, the heat pipe receiver has the important advantage over directly-illuminated tube

receivers of nearly isothermal operation even though the incident solar flux distribution is non-uniform. Also, the excellent heat transfer characteristics of the liquid metal allow a very small receiver, and therefore minimize heat losses. The heat pipe receiver allows the receiver and heater head of the engine to be independently thermally optimized, leading to high receiver thermal transport efficiency. It is essentially an adaptation of heat pipe technology to the peculiar requirements of concentrated solar flux, and provides many advantages over conventional heated tube receiver technology.

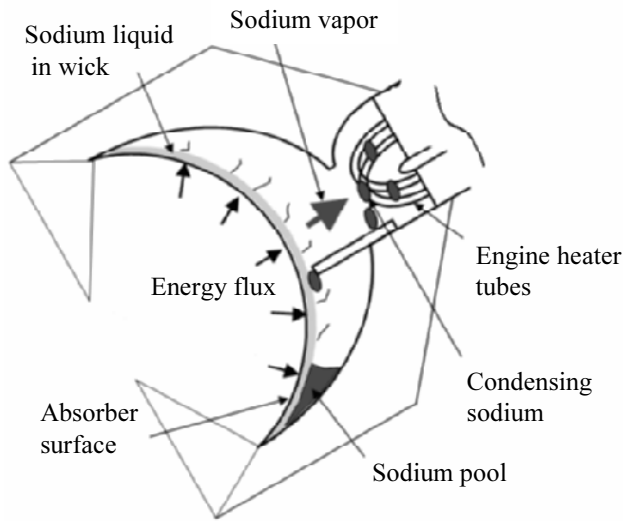


Fig. 1: Schematic of a typical heat pipe receiver.

In dish/stirling system, heat loss from the receiver aperture is an important factor which influences the efficiency. The heat pipe receiver has an open cavity formed by the absorber and a cylindrical insulation board sidewall section. Minimizing and predicting energy losses by natural convection are important design criteria in dish/stirling system. During the operation of the solar dish system, convection heat transfer due to buoyancy force occurs inside the receiver cavity between the inner surface and the surrounding. Accurate calculation of convection loss through the aperture is need for proper prediction of the receiver heat transfer and further the overall performance of the system. In this paper, a numerical study on the major convection heat loss from a heat pipe receiver of dish/stirling system is presented. The investigation conclusions can be used to guide the heat pipe receiver design and application.

2. MODELING AND SIMULATION

The convective heat transfer coefficient from the heat pipe receiver cavity to the surroundings is difficult to characterize. Most heat loss correlations of open cavity have been developed for directly-illuminated tube receivers which are generally cubical geometries or without apertures [6-8]. The investigation should not be suitable for the heat pipe receiver. For studying the heat loss of heat pipe receiver, a computational fluid dynamics (CFD) software package Fluent 6.1[9] was used to numerically simulate the natural convection of heat pipe receiver for dish/stirling system.

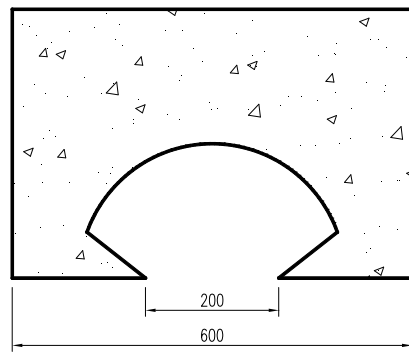
2.1 Problem Formulation

To investigate the convection heat loss of heat pipe receiver, a geometrical model is created. The schematic of the heat pipe receiver considered for simulation is shown in Figure 1. In the two dimension model, the absorber has a 200 mm radius of curvature and 70 degree half angle, resulting in a 376 mm rim diameter(d_r). The receiver cavity was formed by the spherical absorber and a cylindrical insulation board sidewall section. The diameter of the aperture was taken to be three different values to study the influence of the aperture diameter:

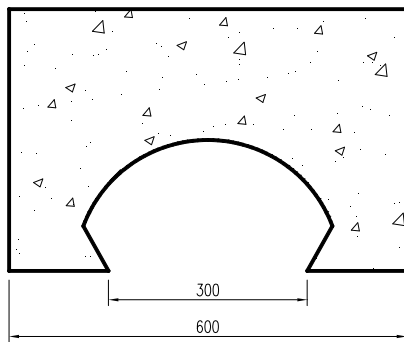
- (a) $d_a = 200$ mm
- (b) $d_a = 300$ mm
- (c) $d_a = d_r$

So the three different geometry model were created separately. Fig. 2 shows details of the three models at the receiver inclination of 90° . The whole heat pipe were enveloped by thick insulation, hence the internal section of the heat pipe could be leaved out of account. So, the model of the heat pipe receiver could be simplified to be idealized geometry as shown in Fig. 2.

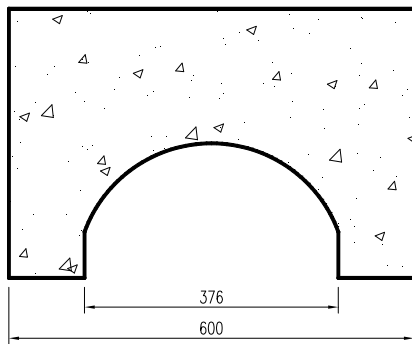
During the numerical computation, the continuity equation, the momentum equations and the energy equation were solved simultaneously in iterative way through the semi-implicit method for pressure linked equation corrected (SIMPLEC) scheme of the Fluent software. The momentum and energy solution controls were of the first order upwind type. The absorber material of the heat pipe



(a)



(b)



(c)

Fig. 2: Idealized geometry of heat pipe receiver as modeled at inclination of 90° .

receiver was stainless steel. The air properties were assumed to be based on incompressible-ideal-gas to simplify the problem. It was assumed in this calculation that the solar flux of the absorber surface concentrated by the parabolic dish is uniform. This assumption means that the temperature of the absorber surface is uniform.

2.2 Boundary Conditions

The absorber surface of the heat pipe receiver was assumed to be isothermal, so the isothermal boundary condition was adapted. The out wall was enclosed in thick enough insulation material so that it could be assumed to be adiabatic. The boundary condition for the computational domain was given by pressure inlet.

3. ANALYSIS OF NUMERICAL SIMULATION RESULTS

The investigation of the natural convection in the heat pipe receiver cavity was based on several different temperatures

and inclination. The temperature was varied from 650°C to 850°C , and the inclination of $0^\circ\sim 90^\circ$ were separately studied to determine the influence to convective heat loss of the receiver. Fig. 3 shows the variation of convection heat loss at various receiver temperatures with different inclinations. It could be found that the natural convection heat loss of the receiver was varying with the variety of the inclinations, also, with the temperature's change. For the operating temperatures, the convection heat loss increases gradually as it varying from 650°C to 850°C . And there was a legible tendency that the heat loss increases with the increase of temperature. For the inclinations of the receiver, the situation is quite the reverse. The natural convective heat loss value is minimum at 90° inclination and maximum at 0° inclination. It indicates the tendency of convection heat loss change during the receiver operating at a whole day. Very early and very late in the day (such as 8:00 and 16:00), when the solar elevation angle was small, the convection heat loss was highest. On the contrary, it was lowest with the large solar elevation at midday.

The investigation to three different aperture diameters was presented too. It was simulated with the absorber surface temperature of 750°C and the inclination varying from 0° to 90° . The variation of convective heat loss with the inclination of receiver for the different aperture diameters was illustrated in Fig. 4. It could be obviously seen that the effect of aperture size on heat loss from the receiver was remarkable. When the aperture was taken to be 200mm diameter, the heat loss was receivable lower. However, the aperture size should be enlarged to suit some specific

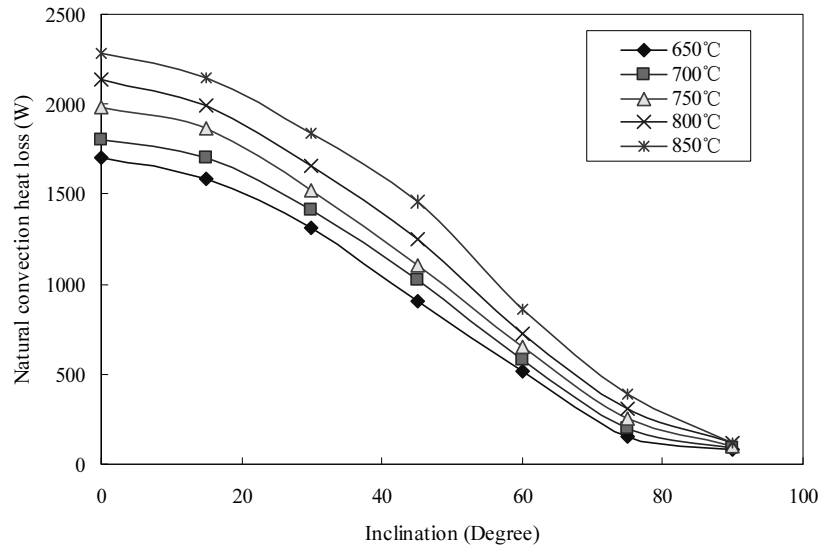


Fig. 3: The convection heat loss at various receiver temperatures with different inclinations.

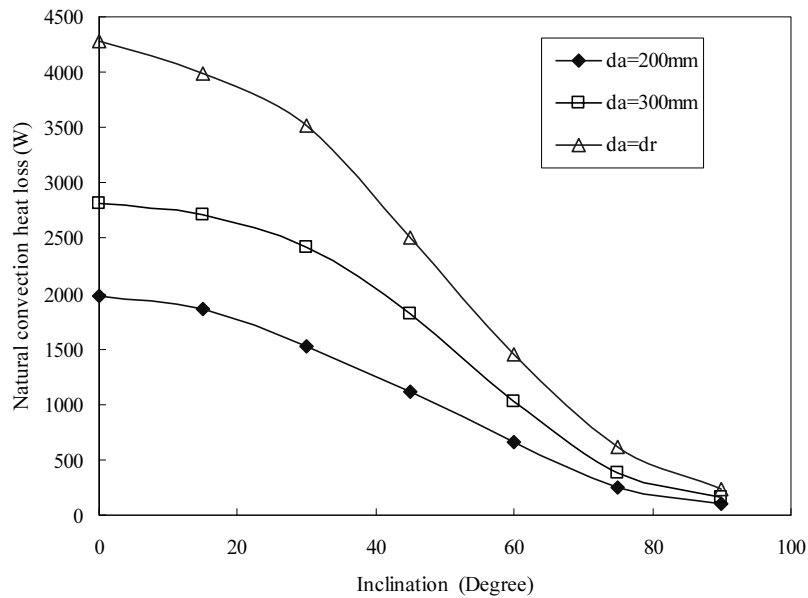


Fig. 4: Natural convection heat loss for various aperture diameters at the absorber surface temperature 750 °C.

situation during the actual operation. It could be identified that the convection heat loss increased remarkably as the diameter of aperture enlarged to 300mm. With the identical tendency, the heat loss value increased to highest when the aperture diameter was taken to be equal to the absorber rim diameter. In any case, the aperture diameter is a critical parameter in design of a solar receiver.

4. CONCLUSIONS

The two-dimensional steady-state numerical model of heat pipe receiver for dish/stirling system has been presented in detail. For different operating conditions, the natural convection heat losses of the heat pipe receiver were

different too. The influence of operating temperature, inclination, and the aperture diameter to the convection were investigated in the paper. As expected, there was a good regularity when simulating the problem. In general, the natural convection heat loss was related with each of the above parameters. It increases with the increase of operating temperature, or with the decrease of receiver inclination, or the increase of aperture diameter. Further improvements are needed on the total heat loss from the heat pipe receiver of different operating conditions.

5. REFERENCES

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